Lawn and Order: Evaluating the relationship between household income and drought restriction compliance in California

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Abstract

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In 2021, the state of California declared a state of emergency for a record-breaking drought and requested all residents to reduce consumption by 15%. The state introduced restrictions on outdoor watering and increased water rates to further curb demand. While restrictions and pricing have been found to be very effective at reducing demand, the restrictions in place affect income classes in different ways. Water use may be very elastic for wealthy households that can afford to pay increased rates and any fines they receive. For lower income households or residents in multifamily housing, it may be a greater challenge to reduce consumption if outdoor watering restrictions do not apply and they cannot afford water efficient technology. To explore the relationship income has with water use, drought restriction compliance, and total reduction, multiple regression models were run for each category for the 2022 year. Population increases lead to higher water consumption, but there is no conclusive relationship between income and water use. There was a positive relationship between water savings and notifications of water waste, climate and drought severity may be responsible for this result. Higher income water districts had the highest median of savings, suggesting that high income households have more opportunities to save water through outdoor watering restrictions and the ability to invest in water efficient appliances.

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Introduction

Drought periods are common occurrences in California, but as climate becomes hotter and drier and population grows, the state will see greater need to incorporate demand management techniques to ameliorate water scarcity (CNRA, 2022). In January through March of 2022, California experienced driest wet season on record and required all residents to reduce their water intake by 15% for 2022 (Newsom, 2022). While the state has plans for increasing water capacity through new water desalination and recycling facilities, intermediate demand management measures of drought restrictions and rate increases have been implemented. In 2022, only twenty-seven of the four-hundred twelve community water districts met the 15% reduction target set by the state (CSWRCB, 2023b). The 15% reduction target may place a higher burden on low-income families or individuals in multifamily housing, as they may be unable to apply outdoor watering restrictions (Haque et al., 2014). Water is priced cheaply so that all may afford this necessary resource (Brookshire et al. 2002), but high-income households may have more price elasticity, meaning that they are willing to pay more to avoid restrictions (Cooper et al., 2011). Income can be linked to both property size and water usage (House-Peters et al., 2010). This thesis will explores the role of income and how it relates to water usage and drought restriction compliance to understand water consumption and savings trends across different income classes.

1.1 RESEARCH OVERVIEW

This study quantifies the relationship between income and water consumption. Within this topic lie three research questions:

1. Does income or population have a greater influence on water use;

2. Is there a relationship between income, water savings percentage, and notification of water waste; and
3. Which income class saves the most water.

The first two questions are analyzed using multiple regression models, while the last question is evaluated using a Kruskal-Wallis and Dunn post hoc test. Population, not income, was found to have a positive relationship to water consumption. Notifications of water waste and percentage of water savings had a positive relationship, based on the literature, we can infer this may be due to climatic conditions of the water district. The percentage of water savings and income did have a positive relationship, indicating that higher earning households save the most water. When making policy decisions on short-term drought restrictions, adopting different reduction goals for land uses may be the most successful approach to reduction.

Literature Review

Due to population growth and dry climatic conditions, residential water demand has increased, outpacing current available supply (Pincetl et al., 2019). Outdoor water uses make up half of residential water consumption and has been greatly influenced by social norms and standards (Ashoori et al., 2016; Sisser et al, 2016). Drought restrictions, in combination with price increases, are effective tools to curb outdoor water consumption demand for most households (Kenney et al., 2008). Many residents are compliant with restrictions and willing to adapt to regulations if they allow for some desired behavior, such as assigned irrigation days or permission to water gardens (Henser et al., 2006). However, there are segments of the population that are willing to pay increased water rates or fines to avoid restrictions and consume as much water as they want. For these wealthy populations, pricing alone may be the most effective in demand management strategy (Cooper et al., 2011). When implementing both drought restrictions and price increases, it is crucial to consider the effect these strategies have on low income and vulnerable communities and include equitable solutions. This study will draw explicit conclusions on the interactions between income and drought restriction compliance.

2.1 CONTEXT: DROUGHT IN CALIFORNIA

2.1.1 WATER SUPPLY & CURRENT DROUGHT

Southern California was developed with the assumption that the state had surplus amount of water, but due to the arid climate and population growth, the state experiences drought periods (Pincetl et al., 2019). With a warming climate, there will be less snowfall, greater evaporation, and higher absorption of water by the atmosphere, vegetation, and soil (CNRA, 2022). California relies primarily on groundwater sources, which accounts for 41% of the state's water (Newsom, 2022). In drought, when surface water is limited, 58% of water comes from ground water sources (Newsom, 2022). By 2040, the state of California's current water supply will likely diminish by 10% due to climate change (CNRA, 2022). To achieve more sustainable water use, California enacts regulations for residents to reduce their water consumption.

The previous drought period in California lasted from 2012-2017, which was set the regulatory framework for the mitigation of future drought periods. In 2015, Governor Jerry Brown signed Executive Order B-29-15, which was the first piece of legislation that required mandatory restrictions on water use in California (Brown, 2015). Governor Brown ordered that residents decrease water consumption by 25% through reduction of use and limits to technology (Brown, 2015). The Executive Order also mandated that all water districts move to conservation or block pricing to encourage residents to further conserve water (Brown, 2015). This pricing method charges residents in a tiered system based on different ranges of usage, creating economic motivation to save water (CSWRCB, 2023a). While the restrictions were successful in demand reduction, after the emergency orders ended, water use climbed back to normal levels (McCarthy and Dallman, 2019). Drought restrictions are very reactionary and do not discourage water wasting behaviors beyond the periods of restriction (Gaughan, 2020).

By October of 2021, all counties in California were declared to be in a state of emergency due to drought conditions (Newsom, 2021b). In March 2022, Governor Gavin Newsom signed Executive Order N-7-22 adopting stringent water conservation policies in response to the most extensive drought in the state of California's history (Nobert, 2022). The state is following a similar restriction model for the current drought period, but has set a reduction goal of 15%, not 25%. Resolution No. 2022-0002 (SCOAL, 2022) was passed with a list of prohibited water uses and management actions, mostly targeting outdoor water uses. The restrictions included increasing communication on the importance of water conservation; limiting outdoor irrigation to certain days or hours of the day; increased patrols to identify water waste; and enforcing water use prohibitions (CSWRCB, 2022b). Water districts were encouraged to set their own more stringent restrictions to reach state goals (SCOAL, 2022).

2.1.2 WATER MANAGEMENT

Water management is broken into two management categories: supply-side and demand management. Both are critical to the sustainability of California's water supply, supply side management adds water sources to supply, while demand side management prohibits waste and curtails user consumption (Bauman et al., 1998). The research presented will focus on the demand management side, specifically the role of drought restrictions in lowering residential water use.

Supply side management increases the available amount of water through the introduction of new sources (Bauman et al., 1998). This includes adding new ground water wells, water recycling, wastewater treatment, or desalination plants (CNRA, 2022). California currently has plans to increase water capacity through these methods, but they will take many years to become operational and are still in the planning phases (CNRA, 2022). In August 2022, the state released a new Water Supply Strategy which sets new goals to diversify and increase water supplies. By 2030, California plans to increase stormwater storage capacity, recycle and use 800,000 acre-feet of water a year, improve the efficiency of current infrastructure, and increase desalination capacity (CNRA, 2022). Through Proposition 68, in 2018 California voters also approved $72 million in funding for loans and grants relating to the construction of water recycling facilities (CSWRCB, 2023g). While supply side management strategies are critical for the long-term success in the provision of water, reduction of residential consumption levels is important to prevent further shortages.

Demand management strategies focus on reducing the water demand of the consumer to lower water use (Bauman et al., 1998). California's water systems were designed and used with the assumption that water is plentiful (Pincetl et al., 2019). As drought conditions intensify, stringent conservation policy is needed to extend current water supplies and support the growing population’s basic needs (Pincetl et al., 2019). There are three conservation strategies the state has employed: rationing, pricing, and conservation education. The state has implemented all three in the current drought in the form of raised rates and penalties for waste, restrictions on water consumption, and outreach efforts (CSWRCB, 2023e). Mandatory restrictions on outdoor watering are seen as the most efficient way to curb demand. Most restrictions target outdoor watering uses, as outdoor watering makes up 50% of water consumption for single-family properties and 30% for multi-family (Ashoori et al., 2016). Restrictions are effective for most of the population and are often followed if easy for the user to implement (Henser et al., 2006). Common restrictions adopted include only permitting lawn irrigation during certain times or days, not allowing the washing of sidewalks or driveways, or requiring pool covers (SCOAL, 2022). Increasing water efficiency and preventing waste is crucial to demand management and supply extension (Bauman et al., 1998), many districts have implemented rebate programs for homeowners that upgrade to water efficient appliances or water-wise lawns. Water efficiency measures are a permanent measure to continue to decrease demand after drought ends.

2.1.3 PRICING

While the current restrictions have curtailed use for the average citizen, California’s wealthy citizens may ignore them to keep their lawns green and their pools filled. Kenney et al. (2008) finds that users are most likely to choose to follow the option that offers fewer barriers to use. This entails that those that can pay more in fines will, and those more sensitive to price will follow the restrictions. Pricing works in tandem with restrictions to keep water consumption lower for many users (Kenney et al., 2008). The value of water is not accurately reflected in the price, as it reflects the cost of providing the service, not the demand or scarcity. Since the 1960's, rates have not significantly increased; water is essential for all life, keeping the rates low is the best option to ensure every resident can maintain access (Brookshire et al. 2002). The state uses a block or conservation pricing method to price water. This pricing strategy sets the price of water by different usage blocks and has been successful in reducing consumption (Maggioni, 2015). With the current drought period, most water districts have increased rates for scarcity, the rate increase is determined by each individual water district (CSWRCB, 2023a). Despite the increased rates and restrictions, some individuals may be ignoring restrictions and going about business as usual.

2.2 CALIFORNIA'S DROUGHT POLICY ACTIONS

In 2015, California governor Jerry Brown issued Executive Order B-29-15 to set in place California's first mandatory drought restrictions. The executive order was prompted by a fourth year of severe drought, greatly straining water resources and availability. B-29-15 set a statewide reduction target of reducing water consumption by 25% of 2013 levels through February 2016 (Brown, 2015). To accomplish the measure, water districts were given the authority to enact restrictions on residential water use. In addition, all water districts were asked to begin reporting monthly water consumption and adjust rate structures to a block conservation pricing model, both permanent measures (Brown). This executive order ushered in the first water efficiency appliance rebate program and waterwise lawn rebates for underserved communities (Brown). Executive Order B-29-15 and related code was the precedent for California's current drought period regulations.

In 2021, the California Natural Resources Agency released the Report to the Legislature on the 2012–2016 Drought to share the strategies employed and effects of the drought on the state. Prior to the current drought period, the 2012-2016 drought was one of the most severe and record-breaking droughts in California's history. A combination of five dry winters and increased groundwater usage left several rural communities without water (CNRA, 2021). Several lessons were learned from this drought period, which have been used to influence current drought policies. The drought led to a requirement for consistent water reporting, so districts can understand the use and efficiency of their water systems. Forecasting water use and supply will ultimately lead to more proactive action and policy (CNRA, 2021). Larger water districts should invest in more regional interconnections to support the transfer of water in emergency situations (CNRA, 2021). The report also details a timeline for making drought management decisions in the second dry year. Having plans in place before a drought period begins reduces the administrative burden and process associated with implementation. Water efficiency standards have also been implemented for appliance requirements. The report serves as a precedent of drought protocols taken and the lessons learned from the last drought period, it has made the state better prepared for the current drought.

McCarthy and Dallman (2019) review the policies and actions taken by the state of California to mitigate the 2012-2017 drought. This drought was the first to implement mandatory water reductions on Californians, increased public policies on water efficiency use and standards. After the emergency proclamation ended water consumption returned to normal levels, suggesting that the public has limited patience to reduce water consumption (McCarthy and Dallman, 2019). Residents had increased awareness of conservation methods and drought after the drought ended, which may help influence long term water sustainability legislation.

McCarthy and Dallman (2019) state that California is moving away from managing droughts as emergencies, but rather a comprehensive approach on water efficiency and management. In the face of growing population and both increasing frequency and intensity of droughts, the state needs to move to long term efforts to increase water efficiency and sustainability.

Executive Order N-10-19 (Newsom, 2019) requests several state agencies to create the state's water portfolio due to increasing stress from climate and the state's growing population. The Water Resources Portfolio requires first an inventory and assessment of current water systems, infrastructure, quality, and demands (Newsom, 2019). The Portfolio would give a long-term management plan for the state's water resources and plans to expand the capacity of current systems (Newsom, 2019). This Executive Order is a proactive stance on the planning of California Water system's and recognizes the need for more expanded capacity solutions as drought frequency increases and populations grow.

Throughout 2021, Governor Newsom declared many counties in a state of emergency due to drought, but in October of 2021, the Proclamation of a State of Emergency was extended to all California counties (Newsom, 2021b). It is noted that multi-year droughts will become more frequent in the face of climate change, with the current drought potentially lasting beyond 2022 (Newsom, 2021b). The Proclamation of a State of Emergency directs all water suppliers to use groundwater to supplement the low surface water reserves in response to the low rainfall and snowpack (Newsom, 2021b). The executive order also prohibits wasteful water use and outlines restrictions on outdoor water consumption, limiting potable outdoor water use to irrigation that does not cause run off (Newsom, 2021b). Local water suppliers and districts are instructed to implement their water contingency plans. The emergency proclamation gives vital instructions for how suppliers should supplement their water shortages and implement demand management.

January through March of 2022 was California's driest wet season on record, prompting Governor Newsom to renew the 2021 emergency proclamation, and give suppliers further instruction with Executive Order N-7-22 (Newsom, 2022). Groundwater accounts for 41% of the state's water use, and 58% in dry periods; about 85% of California's public water systems rely on it as the primary water source (Newsom, 2022). The executive order calls on residents to voluntarily reduce their water consumption by 15-20% to maintain the stability of water sources. Water suppliers are asked to voluntarily invoke more stringent local regulations based on a 30% water shortage than use the restrictions outlined in the administrative code (Newsom, 2022). The authorization is given to water districts for hauling water by truck or bottle for domestic purposes from other water basins. This is limited to areas where water quality or shortage is extremely dangerous and for the sole purpose of human consumption, cooking, and hygiene (Newsom, 2022). N-7-22 limits the drilling of new groundwater wells to ground water sources that are not under stress and that do not pose a threat to drying surrounding wells (Newsom, 2022). Newsom details regulations to assist with groundwater recharge and sustainability. This executive order places a focus beyond individual action to water supplier action and groundwater management.

At the first 2022 meeting of the State Water Board, Resolution No. 2022-0002 was passed to enact emergency conservation regulations in response to the ongoing drought. The emergency regulations mostly target outdoor water uses and infrastructure, as it makes up 50% of daily use (CSWRCB, 2022a). In the restrictions, watering of impermeable surfaces, such as sidewalks, is prohibited as is any irrigation that causes substantial runoff (CSWRCB, 2022a). The regulations prohibit individuals from watering turf within 48 hours of substantial rainfall of a ¼ inch or more. The code allows for certain behaviors with water conserving equipment, such as washing a car using a hose with a shut off valve, or filling a fountain if it has a recirculation pump (CSWRCB, 2022a). Homeowner's associations are not allowed to penalize or fine homeowners that follow the emergency regulations, even if the interest of conservation violates Homeowner Association agreements (CSWRCB, 2022a). The drafted restrictions were adopted Administrative Law in June of 2022.

The June 2022 adoption of Office of Administrative Law 2022-0606-03 adds to the regulations set in Resolution No. 2022-0002. The policy requires all districts to submit a contingency plan by June 1st with the district's strategies to reduce water consumption by 10-20% (SCOAL, 2022). The contingency plans submitted must include a supply and demand assessment to map out district-wide savings and conservation efforts. All districts were required to adopt a drought level 2 plan to reach water savings targets (SCOAL, 2022), which include increasing communication on the importance of water conservation; limiting outdoor irrigation to certain days or hours of the day; increased patrols to identify water waste; and enforcing water use prohibitions (CSWRCB, 2022b). The irrigation of non-functional turf with potable water in industrial, commercial, or institutional sectors is banned under this code amendment. This law is currently in effect until June of 2023, and may be renewed depending on drought conditions at that time (SCOAL, 2022).

2.3 WATER USE

In California, water use is split between three types of land uses: 50% in environmental, 40% in agricultural, and 10% in urban (Mount and Hanak, 2019). Within the urban sector, residential land use makes up 64% of water consumed; institutional and commercial using 23%, and 6% industrial (NRDC, 2014). In total, 70% of outdoor water consumption in urban land use falls in the residential category, which accounts for about half of all urban water use (NRDC, 2014). California has seen a declining trend of residential water use since 1990 due to drought restrictions, efficiency mandates, and pricing incentives (Mount and Hanak, 2019).

Most water used indoors comes from bathroom appliances with toilets being the largest consumer. The average American family uses up to 138 gallons of water indoors daily (Water Research Foundation, 2016), Figure 1 details how water is used within the household. Indoor household water use has reduced by 22% from 1999 levels (177 gallons per household per day) due to regulatory action from the Energy Policy Act, which regulated flow rates for toilets, showers, and faucets (Water Research Foundation). The efficiency standards and interest in awareness from legislation has increased the availability of water efficient appliances. As of 2016, 46% of single-family homes have a efficient clothes washer, 37% with efficient toilets, and 80% with an efficient shower (Water Research Foundation). As these technologies improve, the Water Research Foundation estimates that indoor water savings could be as great as 35-40% of 1999 levels. Indoor water use is in a declining trend, and water use reduction will increase from further expansion of technology.

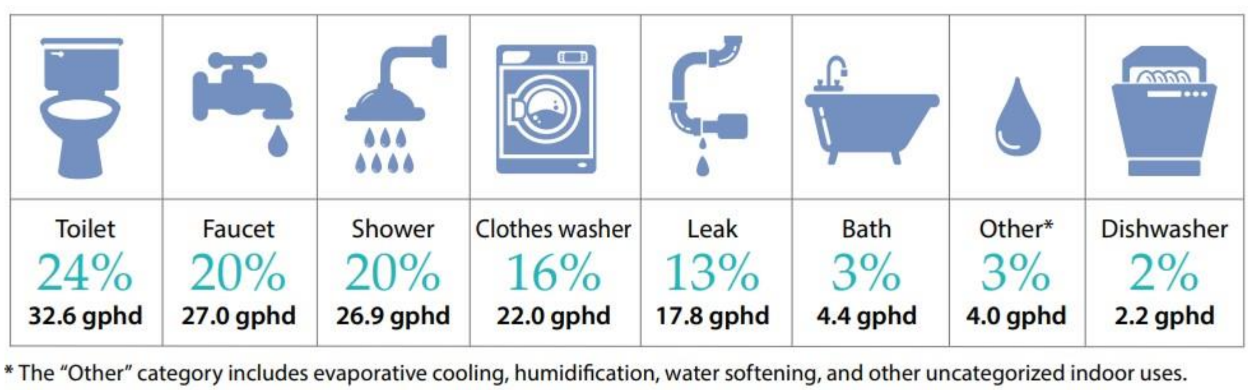

Figure 1: Breakdown of indoor water uses (Water Research Foundation, 2016).

Population growth is a major factor influencing water demand. Water demand is driven primarily by population change and is not influenced by varying climatic conditions (Ruth et al., 2007). The best way to combat high demands from growth is by investing in capacity increasing infrastructure and implementing aggressive demand management strategies (Ruth et al., 2007). California is using both of Ruth et al.'s suggestions, with aggressive demand management currently in place through drought restrictions. Population growth in California may add additional stressors onto the water supply, and it is important to understand how population increases impact water use.

Private swimming pools are more likely to occur on large, high-income properties and more common in warm climates (Wentz and Gober, 2007). Swimming pools increase outdoor water demand by 15-20% (Fisher-Jeffes et al., 2015). Even if used with conservation methods (such as using pool covers), pools place a large strain on water supplies and should not continue to be built in water scarce regions (Fisher-Jeffes et al., 2015).

Lawn care is still a priority to many homeowners in times of drought, with residents defaulting to alternative, yet wasteful techniques to keep lawns green. Sprinkler bans may be less effective than restricted watering days, and some residents will go out of their way to keep lawns green with hand watering (Brennan et al., 2007). Restricted watering days are important as they give some freedom to homeowners to keep their yards alive. Restrictions receive less resistance if they are not extremely stringent and allow for some desired behavior (Kenney et al., 2007). Ordinances and policies for irrigation and grass height highly influence homeowner lawn maintenance and have built social norms for green lawns across the U.S. (Sisser et al., 2016) Lawn ordinances create neighborhood normative expectations, encouraging individuals to maintain sod lawns (Sisser et al., 2016). Homeowners will often emulate the water use and lawn care techniques of their neighbors (Wentz and Gober, 2007). The prioritization of water use for sod lawns is not sustainable for long term drought management and social norms and ordinances need to be broken down to encourage water friendly landscaping.

Maggioni (2015) compares demand management strategies to determine which is the most effective at conserving water: pricing, policy mandates, or subsidies/rebates for water saving devices. Policy mandates were the most effective strategy in curbing demand, followed by pricing (Maggioni, 2015). In the study, rebates had the lowest water saving yield, as the qualifying appliances have a low water saving yield and may take years to pay for itself in savings (Maggioni, 2015). This does not imply that rebate programs are not valuable or effective at water conservation, just that there are lower savings in water compared to other demand management methods.

Many socioeconomic and land use factors determine a properties water demand. Property size and land uses are strong determinants of demand, with single-family homes having higher demand than dense residential development (House-Peters et al., 2010). Ashoori et al. (2016) evaluates the influence of price, climate, conservation, and population on water demand for different land use types to determine which is the most successful at reducing demand. Price increases and conservation lowered consumption for all segments, except single family homes (Ashoori et al., 2016). Single-family residential demand only went down with increased precipitation.

2.4 RESTRICTION COMPLIANCE

When drought restrictions were implemented in 2021, those that could afford to paid fines for overuse, rather than reducing their water usage. Romo (2022) exposes several Southern California celebrities that were fined for over consumption of water in the summer of 2022. The article compares celebrity water usage with the average water usage. Most fines given were under $2,000, which is a paltry amount when compared to the wealth of the offenders. Romo demonstrates that the current fine structures are not significant enough to curb demand for high-income violators. These populations are not sensitive to price increases, water is an elastic expense that they are willing to pay for their desired use.

To some, drought restrictions may be viewed as inconvenient or an infringement of rights, some individuals are willing to pay fines or would accept increased rates to avoid drought restrictions all together. Socioeconomic and land use factors such as households with lawns, high education levels, high annual income and residence in areas with long term restrictions had a higher willingness to pay (up to 25% more) to avoid drought restrictions (Cooper et al., 2011). Residents are more willing to adjust to restrictions due to personal moral attitudes or if the restrictions do not affect them individually (Henser et al., 2006). Populations are more willing to adapt to restrictions if policies allowed for certain behaviors, such as watering gardens or adjusting outdoor watering schedules to certain days of the week (Henser et al., 2006). High water users are more likely to respond to price increases than low users, but most responded to the demand management technique (pricing or restrictions) that gave them the lowest barrier to use (Kenney et al., 2007). Current California restrictions do have allowances for desired behavior to ease the transition into waterwise behaviors. Allowing restricted watering limits potential savings but may increase rates of compliance.

Multi- and single- housing respond to demand management measures differently. Mini et al. (2014) evaluates what level of drought restrictions are most effective on curbing demand for outdoor watering in single family homes. The article found that stringent outdoor watering mandates in combination with increased pricing were the most efficient in reducing water use in single family homes (Mini et al., 2014; Kenney et al., 2007). Voluntary restrictions are not effective in reducing water use at a municipal level (Mini et al. 2014). Areas with higher temperatures and more severe drought restrictions save more water, signifying that climatic conditions do play a role in demand management (Haque et al., 2014). Single-family homes experience greater savings than multi-family housing as most restrictions target outdoor water use (Haque et al., 2014; Mini et al., 2014). Severity levels of restriction and climatic conditions influence awareness and effort to save water.

2.5 WATER SAVINGS BY INCOME CLASS

Water rationing policies have different effects on low, medium, and high income earning households. Pérez-Urdiales and Baerenklau (2020) find that most water districts were able to meet the mandatory restrictions, but vulnerable populations such as the poor, elderly, households with children, and Hispanic populations faced a larger burden with the restrictions and were not able to meet district goals. Water demand differs due to social and demographic factors such as employment status, age, ethnicity, political party, and religious affiliation (Krause et al., 2003) Water managers should be flexible when setting use reduction targets and tailor policies to these demographics (Pérez-Urdiales and Baerenklau, 2020). Water rationing is a common response in areas with drought stress, but the effects of rationing may not be equitably shared by all residents. Rationing affects the lower income water usage the most, where higher income classes felt like rationing did not change their water consumption (Del Grande et al., 2016). Rationing should be felt by all residents equally and may need to be more stringent for high earners that have greater water savings potential.

Gaughan (2020) used the South African Day Zero Water Crisis as a case study to criticize demand management techniques when a city is out of water. Drought restrictions are reactionary, temporary measures that do not influence long-term patterns of use, despite water demand increasing 6-7 times in the 21st century (Gaughan, 2020). In the Day Zero Water Crisis, effects of the shortage were felt differently by different income classes. Wealthier households were always able to increase rations through procurement of water through private sources, checking into hotels, and accessing their own sources of groundwater (Gaughan, 2020). The article boasts the benefits of privatization to increase prices to discriminate overconsumption and promotes value-added taxation (like carbon taxes) as a potential demand management solution. The article is a case study for what could happen during absolute shortage but undervalues water restrictions and sets unrealistic targets for pricing.

2.6 CONCLUSION

Existing studies suggest that drought restrictions, in combination with increased pricing, can be the most effective method to save water, unless segments of the population choose not to follow them. The choice to comply with drought restrictions depends on several socioeconomic factors, including income, education level, and political opinion. Most drought restrictions target outdoor water uses, and if followed single family homes see the highest amount of water savings during the period of restriction. Rationing techniques can be inequitable to socially vulnerable communities, placing a greater burden to conserve water than other residents. Further research is needed to quantify the relationship between income, water consumption, and drought restriction compliance.

Methods

This study evaluates income as a factor in residential water usage and drought restriction compliance. There are three subsections of the study: water use, drought restriction compliance, and water reduction by income level. The study uses quantitative methods to assess the relationship between income and each subsection during the 2022 year. The research examines if a relationship occurs between income and all dependent variables, the type of relationship present, and its strength.

3.1 RESEARCH QUESTIONS AND HYPOTHESES

The ***first research <u>question</u>*** asks if there is a relationship between water consumption and income, or if consumption is derived from population alone. Temporal influence of drought restrictions and use at district vs. individual level will also be evaluated. It is hypothesized to see income have a greater influence on water consumption than population, and that the relationship between income and consumption will be positive. This would indicate that as income increases, water use also increases. Water use changes with different land uses, with single-family homes having the highest demand for water (Ashoori et al., 2016). Higher earning households are more likely to own single family homes, and wealth may be an indicator of property size and outdoor features. A second expected result is to see a weaker relationship between income and water usage for the post-restriction data set than the pre-restriction data set. This would reflect the water reduction from the restrictions and may show a change in relationship after restrictions are implemented. Per capita water use should have a stronger relationship with income than the district data, as it is at a more precise scale.

The ***second research question*** assesses how income relates to measures of drought restriction compliance measures, which include number of waste notifications and percentage of water saved. It is expected to see a strong positive relationship between income and both dependent variables. While some notifications of water waste are a result of infrastructure failure, there may also be some choosing to pay their way out of restrictions. This may be a smaller proportion of the total population, but some penalties may be within the willingness to pay of higher earning households. According to Cooper et al. (2011) several demographic factors may influence willingness to pay to avoid restrictions; including education, having a lawn, length of restrictions, and high income. If the first hypothesis regarding income and consumption is true, it is likely that high earning households that follow restrictions will see significant outdoor water savings. Most drought restrictions target outdoor water uses, and the difference in savings between multi-family and single-family homes is severe (Haque et al., 2014) Higher income households may also have greater capital to invest in water saving appliances for their homes.

The ***third research question*** assesses the differences between water savings and income levels. It is hypothesized that income and savings will have a strong positive relationship, which would indicate that the biggest difference in savings would be between high- and low-income water districts. As previously mentioned, higher income households have more opportunities to save water through indoor technology and complying with outdoor restrictions. Haque et al. (2014) establishes that residents of multi-family homes have fewer outdoor watering opportunities, which reduces their savings. Pérez-Urdiales and Baerenklau (2020) also found that vulnerable and disadvantages populations struggled to meet district goals, in part due to the inability to afford water saving technologies or lack of communication in their native language (if English was a second language).

3.2 DATA SOURCES AND MANAGEMENT

California is selected as a general study area, as all water districts report to the same state agency and implemented Executive Order N-7-22. Out of the 412 water districts, only 338 community water districts reported consumption data that will be used to calculate the district's water use and savings variables. Key data and calculations will all be compiled into a Drought Data csv and used for quantitative analysis. Table 1 displays a table of all variables used in the study, their data sources, units, and derivations. Five data sets were used in the analysis to calculate key variables:

- June 2014 - February 2023 Urban Water Supplier Monthly Reports (CSWRCB, 2023b);
- October 2020 - December 2022 Water Shortage Drought Response Actions (CSWRCB, 2023c);
- Individual Income Tax Statistics - 2020 ZIP Code Data (SOI) (Internal Revenue Service, 2021);
- System Area Boundary Layer (SABL) Look-up Tool (CSWRCB, 2023d);
- And California Zip Code Geodata (Dixon, 2021).

Variable	Source	Descripton	Derivation	Unit
PWSID	Water Shortage Drought Response Actions	Public Water System ID Number	N/A	N/A
WATER_SYS	Water Shortage Drought Response Actions	Name of Water System	N/A	N/A
COUNTY	Water Shortage Drought Response Actions	Name of counties served	N/A	N/A
TPop	Water Shortage Drought Response Actions	Total Population of water district	N/A	Number of People
Notifications	Water Shortage Drought Response Actions	Number of Notifications of Water Waste for 2022	Monthly data was summed into annual data for 2022	Number of Notifications
Income	Individual Income Tax Statistics - 2020 ZIP Code Data	Estimated income for Water District	Total income value was divided by total number of returns to estimate per capita household income for each zip code	U.S. Dollars
IncLvl	World Economic Forum	Low-, medium- or high income level	Assigned to water districts based on estimated income	Categorical
Residential	Urban Water Supplier Monthly Reports	Coefficent for rate of residential use	N/A	Percentage
BaselineGallons	Urban Water Supplier Monthly Reports	Total gallons of water the district consumed in 2020, prior to the drought restrictions	Multiplied by the residential coefficient to remove consumption by other land uses	Gallons
Gallons	Urban Water Supplier Monthly Reports	Total gallons of water the district consumed in 2022	Multiplied by the residential coefficient to remove consumption by other land uses	Gallons
PerCapGal	Derived from existing variables	Total gallons used per person in 2022	2022 Gallons divided by Total population	Gallons
H2OReduction	Derived from existing variables	Percentage of water use reduction from 2020 to 2022	2022 Gallons divided by BaselineGallons multiplied by -1	Percentage

Table 1: Data dictionary for all variables and data used in analyses.

The June 2014 - February 2023 Urban Water Supplier Monthly Reports (CSWRCB, 2023b) was the primary data set for all water consumption variables. The dataset reports out the monthly water consumption for land use types for all community water districts in California. Figure 2 details the derivation of the variables Water reduction percentage, Baseline cumulative gallons, 2022 cumulative gallons, and per capita water use from this data set. For a complete data dictionary for the June 2014 - February 2023 Urban Water Supplier Monthly Reports dataset, please refer to Appendix A.

The October 2020 - December 2022 Water Shortage Drought Response Actions (CSWRCB, 2023c) details the types of actions each water district implemented for the drought. This data set contained the population data for each water district, which was used in the analysis, as the Total Population Variable. The Number of Water Wasters Notified was summed into total 2022 notifications of waste for each water district. Total number of penalties was considered for the compliance variable but was not used as not all water districts issued penalties for compliance.

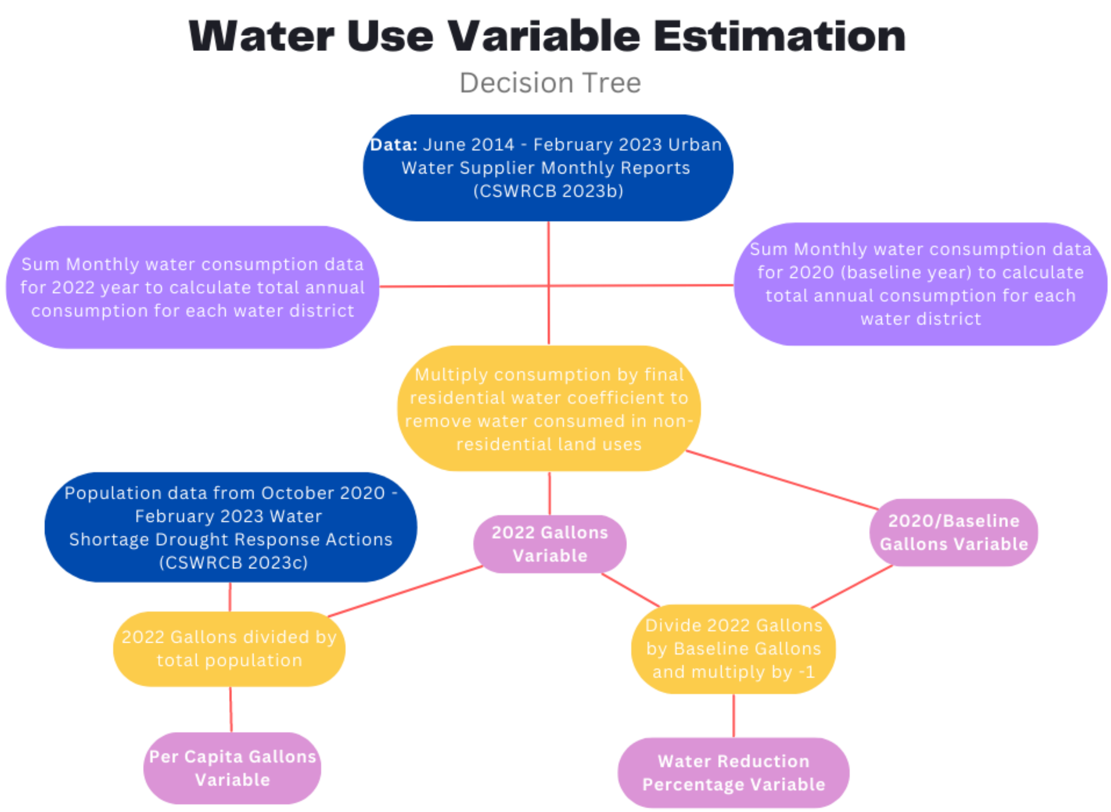

Figure 2: Decision Tree for the calculation of Per Capita Gallons, 2022 Gallons, Baseline Gallons, and Water Reduction Percentage. The dark blue bubbles indicate a data source, lavender for consolidation, yellow for calculation, and pink for final variables.

The complete data dictionary for the October 2020 - December 2022 Water Shortage Drought Response Actions can be found in Appendix B.

Water district boundaries did not often coincide with other geographic boundaries such as census blocks, zip codes, counties, or municipalities. Estimation was required to find an income value for each water district. Household income was estimated using the Total Income by zip code data from the Internal Revenue Service (2021). The process for income estimation is detailed in Figure 3. Water district income was calculated by taking the average income for all zip codes that intersected the water district boundary (Figure 4). California Zip Code geodata

(Dixon, 2021) and the System Area Boundary Layer Look-up tool (CSWRCB, 2023d) were used to map the zip codes and water district boundaries for income estimation.

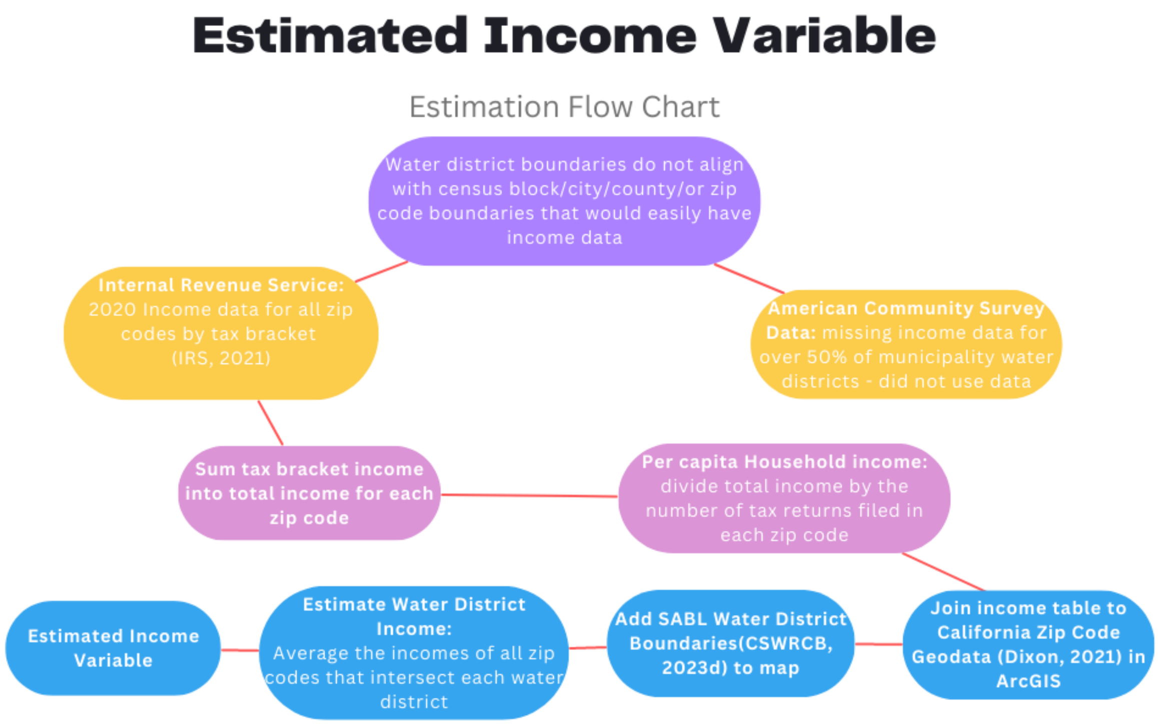

Figure 3: Income Estimation Process

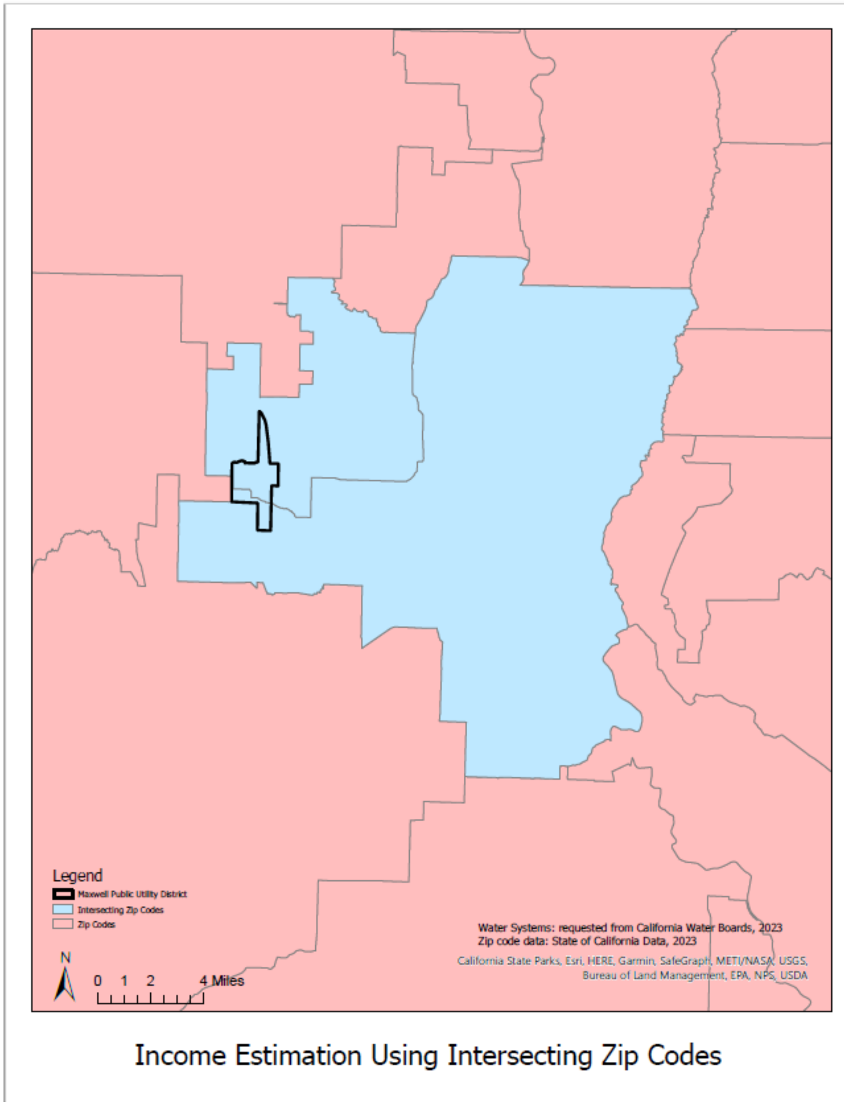

Figure 4: Zip code selection for income estimation, zip codes intersecting a water district were averaged to provide an estimated per capita district income.

Two outlier water districts, the City of Fresno and Palmdale Water District, were removed from the data as they had a significantly higher number of notifications and penalties. Most water districts had 10,000 or less notifications of water waste and 1,000 or less penalties, but the City of Fresno had 141,205 notifications and 121,428 penalties; Palmdale Water District had 1,503 notifications and 175,783 penalties; and the Las Virgenes Municipal Water District had 44,348 notifications and 34,891 penalties (CSWRCB, 2023c). Both the City of Fresno and Palmdale Water District use a flat fee system for penalties rather than fine each excess gallon

(City of Fresno, 2023; Palmdale Water District, 2022). Flat fees are ineffective at promoting water conservation, tiered pricing and pricing per unit of use has been identified as the most successful pricing method to conserve water (Maggioni, 2015). The City of Fresno's penalty model starts at a $25 fee, which increases by $25 increments up to $100. If a customer reaches the $100 penalty and continues to over consume, the fine remains at $100 (City of Fresno, 2023). The City of Fresno's current penalty system may lie well within the willingness to pay for it's customers and would therefore not be effective at discouraging repeat offenses. The Palmdale Water District also uses a flat fee system, but fines are significantly more severe with the first offense starting at $50, then increasing to $250, then $500, and finally $1,000 which includes a disconnection of service (Palmdale Water District, 2022). While Las Virgenes Municipal Water District was also a significant outlier, they fine by excess billing unit of water, with an increased cost of $2.50 per excess unit on the first penalty and $5.00 per excess unit of repeat offenses (Las Vigenes Municipal Water District, 2023). As Las Virgenes bills by unit instead of flat fee fines and is a higher income district, it was determined that it was relevant to the study and not removed.

3.3 METHODS OF EVALUATION

We first determine the relationship between income and water use. Three multiple regression models are used to determine relationships of significance between water usage variables (Baseline/2020 Cumulative Gallons, 2022 Cumulative Gallons, or Per Capita Gallons) as a product of the independent variables (Income and Total Population). As populations differ greatly between districts, population is included as a control variable. Total Population is in terms of number of people served and is not at household scale. It is important to note that each water use variable is a summation of indoor and outdoor water uses, and totals for indoor and outdoor use separately are not available. The water use variables are then split into different regressions models to determine if the relationship changes before or after drought restrictions were in place. Separating Per Capita Gallons allows comparison between relationship of income with scales of individual and district level water use.

Secondly, we assess the compliance with water restrictions. A multiple regression matrix is created to assess the relationship between Income, Population, Notifications of non-compliance, and Percentage of Water Reduction. This model gives correlation values between all variables (R correlation value), as well as the significance of the relationship (p-value). The correlation matrix calculates correlation values using the Pearson correlation coefficient. The multiple regression model was selected as it shows the relationship between all variables of interest and would show if one might influence over relationships. While non-compliance penalties quantify repeat offences, Notifications of water waste was chosen as an enforcement variable as some districts were not fining penalties during lower drought stages. The Water Reduction Percentage variable shows if increased savings are influenced or correlate with increases in population or income.

The final analysis looks at the differences between water savings by income class. Estimated income is transformed into an ordinal variable with three levels to represent low-(1), middle-(2), and high-(3) income levels. The income levels are split using values from the World Economic Forum (2022) values for low (less than $52,000), medium ($52,000-$156,000), and high (greater than $156,000) income in the United States. Water reduction values were plotted into a box and whiskers graph split by income level to display the distribution of the data. To analyze the differences in water reduction between income levels, a Kruskal-Wallis analysis is used. The data is non-parametric, as it is normally distributed, but fails the Levene’s test for equal variances. The Kruskal-Wallis test is able to identify if there are differences of the median, but not what the differences are. To calculate the differences between income levels, the Dunn test is used as a post-hoc. The Dunn test determines what the differences of water savings were between each pair of income classes.

3.4 DATA AND MODEL LIMITATIONS

The district scale may not be the most precise scale to analyze the data. When looking at the model from across all water districts, data trends within individual districts may be generalized or hidden as it is a large scale. The most precise method would be to conduct the analysis on one water district, rather than all community water districts in the state. Unfortunately, due to customer confidentiality, water districts initially contacted were not able to share customer use or notification data by parcel and did not collect this data by census tract or zip code.

Income data was estimated, as many water district boundaries did not follow firm zip code, county, or census tract boundaries. By estimating the mean household income by averaging intersecting zip codes, zip codes with a higher land mass had less weight in the calculation. Evaluating average property value instead of income was considered, but as property valuations occur every five years, the data may not be as current as annual IRS per capita income.

The comparison between per capita use and income are set at different scales. Per capita water use represents the consumption for all individuals within the water district, where income was estimated on a per capita scale by household. The Urban Water Supplier Monthly Reports dataset was limited to total population served and did not disclose the number of households served. This may lead to inaccurate results or a smaller r^2 value, indicating a small representation of data in the model. Per capita use does not control for household size.

Drought restriction stage or area climate was not included in the model. As all data was collected over an annual period, the restrictions in most districts changed depending on season and the microclimate of the water district. Some districts never moved beyond early stages of restrictions, while several others in hotter areas moved to late stage or highly strict regulations during the summer. Several districts in cooler climates did not start reporting monthly water usage and compliance data until the statewide executive order was implemented in March of 2022 (CSWRCB, 2023b). Trends in usage, savings, and compliance highly vary between summer and winter, and are generalized in annual data. Climate and seasonality likely play a major role in water consumption but was not included due to the amount of variation over an annual basis.

The impacts of the COVID-19 pandemic were not evaluated in the study and may be a source of additional error. The COVID-19 pandemic increased the amount of residential water consumed in 2020, as many individuals were working from home and not commuting (Irwin et al., 2021). Water savings from 2020 to 2022 may be higher than if 2019 was a base year. The California stay at home orders were relaxed in 2021, allowing schools and offices to reopen, which led to less water use at home (Newsom, 2021a).

Results

Four multiple regression models were created to assess the relationship between income with both water use and drought restriction compliance. A Kruskal-Wallis test and Dunn test for pairwise comparisons were also used to test the differences between income classes and water reduction values. The analysis was done at different time periods and scales to determine if drought restriction implementation influenced district water use or if the relationship differed between water district and individual usage scale. Water consumption was found to be a significant product of population, not income. Water reduction and income had a positive relationship, with the greatest difference in water savings between high- and low-income classes. A positive relationship of significance was also found between water reduction and notifications, indicating the districts with increased water savings receive more notifications of waste.

4.1 WATER USE

The multiple regression models for Baseline Gallons (Figure 5) and 2022 Gallons (Figure 5) had identical results, indicating that there is no temporal difference in relationships before and after drought restriction implementation. The Baseline Gallons variable refers to 2020 or pre-drought restriction time period, while the 2022 Gallons variable refers to the post-drought restrictions period. The data sets came from the June 2014 - February 2023 Urban Water Supplier Monthly Reports (CSWRCB, 2023b), which report the water use for each water district. The implementation of drought restrictions did not alter the relationships between district level water use with income and population. Both multiple regression models were found significant with p-values of 2.2e-16, and an R^2 of 0.93, indicating that 93% of the data is represented in the models.

The p-value differed for Income in both the pre- and post- restriction linear regressions but was found insignificant in both models. Baseline Gallons (2020, or pre-restriction data) had a p-value of 0.742 and 2022 Gallons (post-restriction period) had a p-value of 0.481 with Income. Income was calculated as a household per capita value for each zip code in California, using the 2020 IRS tax return data (IRS, 2021). As water district boundaries did not align with zip codes, the income values for all intersecting zip codes were averaged. The large amount of derivation to estimate income may be responsible for the insignificant results. The large scale may also mute household usage and income differences and generalize the data. We cannot determine if income has a relationship to water use across California's water districts.

The relationship between Baseline Gallons (pre-restrictions) and 2022 Gallons (post-restrictions) with Total Population was found significant at a 95% confidence level with a p-value of 2e-16. The Pearson correlation coefficient for Total Population with both water use variables had a positive r correlation value of 0.964, indicating that there is a very strong, positive relationship between Total Population with both Baseline Gallons and 2022 Gallons. The relationship demonstrates that as a water district experiences population growth, water consumption also increases. There was only one data set used for Total Population, from the June 2014 - February 2023 Urban Water Supplier Monthly Reports (CSWRCB, 2023b), which reflects the 2022 population for each monthly report. As the research looks at a two-year timeframe, population would need to change significantly across all water districts to influence the relationships. There is not a relationship change with the Total Population variable from 2020 to 2022, likely because the population data is the same. We can conclude that population is the primary driver of water usage across all community water districts.

```
Call:
lm(formula = BaselineGallons ~ Income + TPop, data = data_use)

Residuals:
       Min         1Q     Median         3Q        Max 
-1.860e+10 -8.073e+08 -3.390e+08  4.902e+08  2.476e+10 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  5.372e+08  2.446e+08   2.196   0.0288 *  
Income      -5.857e+02  1.782e+03  -0.329   0.7426    
TPop         4.481e+04  6.667e+02  67.209   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.866e+09 on 335 degrees of freedom
Multiple R-squared:  0.931,  Adjusted R-squared:  0.9306 
F-statistic:  2259 on 2 and 335 DF,  p-value: < 2.2e-16
```

Figure 5: Multiple regression model of Baseline Gallons with Income and Total Population. The use data is from 2020, before drought restrictions were in place.

```
Call:
lm(formula = Gallons ~ Income + TPop, data = data_use)

Residuals:
       Min         1Q     Median         3Q        Max 
-1.942e+10 -7.454e+08 -2.725e+08  5.498e+08  2.481e+10 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  5.069e+08  2.357e+08   2.150   0.0323 *  
Income      -1.210e+03  1.717e+03  -0.705   0.4816    
TPop         4.289e+04  6.425e+02  66.756   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.762e+09 on 335 degrees of freedom
Multiple R-squared:  0.9301, Adjusted R-squared:  0.9297 
F-statistic:  2229 on 2 and 335 DF,  p-value: < 2.2e-16
```

Figure 6: Multiple regression model of 2022 Gallons, the data used represents water used after drought restrictions were in place.

The multiple regression model for Per Capita Gallons with Total Population and Income (Figure 7) was not found significant with a p-value of 0.915, and an R^2 of 0.0005, indicating that 0.05% of the data is represented in the model. Per Capita Use was calculated by dividing the 2022 Gallons variable by the water district's population. This model differs from the previous two regression models as it attempts to quantify individual water consumption, instead of district consumption. The Per Capita variable solely looks at water consumption at an individual level with the district level income estimates. The derivation does not control for household size, where larger households may require more water for everyday needs. By calculating on a per capita basis, the household variation on water consumption is likely removed or reduced. District level data is more critical as it is at the same scale as the population and income variables. As the Per Capita Gallons model represents very little data and both independent variables had insignificant p-values, we cannot firmly determine if there is a relationship between Per Capita Water Use with either Income and Total Population.

```
Call:
lm(formula = PerCapGal ~ Income + TPop, data = data_use)

Residuals:
    Min      1Q  Median      3Q     Max
 -74567  -38932  -20860   -4515 7073856

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.651e+04  3.317e+04   2.307   0.0217 *
Income      -5.303e-02  2.417e-01  -0.219   0.8264
TPop        -3.204e-02  9.040e-02  -0.354   0.7233
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 388600 on 335 degrees of freedom
Multiple R-squared:  0.0005302,  Adjusted R-squared:  -0.005437
F-statistic: 0.08886 on 2 and 335 DF,  p-value: 0.915
```

Figure 7: Multiple regression model for Per Capita Gallons

Within the water use section, a clear relationship between water use and income level could not be identified. When comparing the water use variables with income, none had significant p values within a 95% confidence. Significant relationships were found between Total Population with both Baseline Gallons and 2022 Gallons. On a district wide scale, population is the key factor influencing district water consumption.

4.2 RESTRICTION COMPLIANCE

Between Income, Population, Water Savings, and Notifications of Waste only two relationships were found statistically significant at a 95% confidence level, these were between Water Savings and Income, as well as Water Savings and Notifications. Figure 8 displays a Pearson correlation matrix from the multiple regression model to show strength of association between all variables.

- r:

	TPop	Income	Notifications	H2OReduction
TPop	1	0.02484	0.03155	-0.00665
Income	0.02484	1	0.0677	0.2443
Notifications	0.03155	0.0677	1	0.1491
H2OReduction	-0.00665	0.2443	0.1491	1

- n:

	TPop	Income	Notifications	H2OReduction
TPop	338	338	338	338
Income	338	338	338	338
Notifications	338	338	338	338
H2OReduction	338	338	338	338

- P:

	TPop	Income	Notifications	H2OReduction
TPop	NA	0.6491	0.5632	0.9031
Income	0.6491	NA	0.2144	5.514e-06
Notifications	0.5632	0.2144	NA	0.00602
H2OReduction	0.9031	5.514e-06	0.00602	NA

Figure 8: Multiple regression correlation matrix for compliance variables. This table displays the Pearson correlation coefficient(r), number of data points (n), and the p-value (p).

Income and Water Savings had a p value of 5.514e-06 and a positive, weak correlation of 0.2443. This indicates that as income increases, water savings across districts also increases. The income dataset is the same derivation of reported IRS zip code data used in previous sections. Water Savings is the percentage of water the district saved in 2022, compared to 2020 levels. The data used for the Water Savings variable is from the Water Supplier monthly reports (CSWRCB, 2023b). Higher income households have greater options in potential savings, as they may be able to significantly reduce outdoor watering and invest in water saving technology.

The relationship between Water Savings and Notifications was significant, with a p-value of 0.00602 and a positive, very weak r correlation value of 0.1491. This relationship informs that as water savings increases, the number of water waste incidents also increases. The relationship is likely influenced by other factors, such as drought restriction stage or climate conditions. The Notifications of waste data comes from the Water Shortage Response data set (CSWRCB, 2023c), the variable informs restriction violators of water waste. The Notifications variable is used as one compliance measure in the analysis, to determine what the relationship documented violations and compliance have with the other variables. This may show the stringency of restrictions and increased communications lead to higher percentages of water reduction.

Total Population had p-values of 0.6491, 0.5632, and 0.9031 with Income, Notifications, and Water Savings, respectively. These relationships are not significant, and we are unable to conclude the relationship. While the population data is the same as that used in the water use section, these relationships differ from that of the use variables in the previous section. Populations of varying sizes are all equally able to respond to measures of restriction compliance. Population density does not determine the amount of water waste, savings, or income a district has.

Income and Notifications had an insignificant p-value of 0.2144, indicating no interaction. People are capable of waste, regardless of income; the lack of relationship may indicate little indifference to the drought restrictions. As both Income and Notifications have significant relationships with Water Savings, the finding of no significant relationship between the two may indicate alternative causation for their relationships with Water Savings.

4.3 DIFFERENCES IN SAVINGS

As there is a positive relationship between Income and Water Reduction Percentage, there are great differences in savings between income classes. The Water Reduction Percentage is the reduction of annual water use from 2020 to 2022. Each water district was assigned an income level from the World Economic Forum based on the district's estimated income. Level 1 or low-income indicates less than $52,000 in annual income; level 2 or middle-income households earn $52,000-$156,000 a year; and level 3 or high-income earners make greater than $156,000 annually. For reference, the median income in California from 2017-2021 (in 2021 dollars was $84,097 (U.S. Census Bureau, 2023). The middle-income class, level 2, had the greatest number of data points and the widest distribution of water savings between the three income classes. High income classes had the highest median of savings but had fewer data points overall than classes 1 and 2. Only 27 water districts achieved the 15% reduction goal (the 0.15 line on Figure 9) in 2022, Table 2 details the income distribution of districts that met the 2022 reduction goal. The middle-income class has the most districts meeting the target, high income had some districts, and low income had only two districts that met the goals.

Income Level of Districts that met 15% Reduction Goal	
Income Level	Number of Districts
1	2
2	16
3	9

Table 2: Income distribution of water districts that met the 15% reduction goal in 2022.

The Kruskal Wallis test determined that there were differences in water savings by the three levels of income class. At a 90% confidence level with a p-value of 0.0004, the Kruskal Wallis test determined that there are significant differences between the three levels of income.

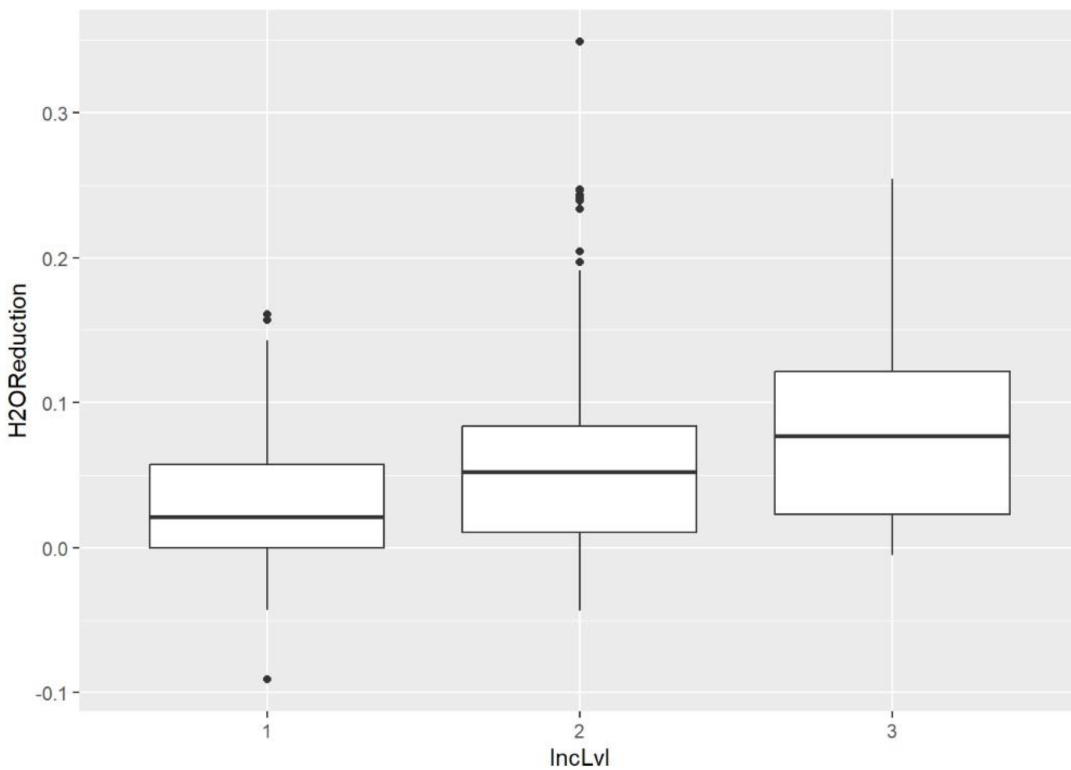

Figure 9: Box and Whiskers plot of water reduction percentage (H2OReduction) by income class (IncLvl). The Water Reduction Percentage is the percentage of reduction of water used from 2020 to 2022. Income is split into 3 levels: Level 1, less than $52,000; Level 2, between $52,000-$156,000; and Level 3, greater than $156,000 annually.

The Dunn test found that all differences between income levels were statistically significant (p -value <0.1). The largest difference between groups (Figure) was between the low-income group (level 1) and the high-income group (level 3); these groups had a z score of -3.917

and a p-value of 0.0002. The moderate difference was between low- and middle-income (level 2) levels, with a z score of -2.691 and a p-value of 0.0213. The smallest difference was between middle- and high-income levels with a z score of -2.360 and a p-value of 0.0546; this difference is significant at a 90% confidence level (p<0.1), but not 95%. Through the pairwise comparisons, the Dunn test confirmed that there are differences between all income level medians and distributions.

	Comparison	Z	P.unadj	P.adj
1	1 - 2	-2.691845	7.105797e-03	0.021317392
2	1 - 3	-3.917996	8.928834e-05	0.000267865
3	2 - 3	-2.360884	1.823145e-02	0.054694364

Figure 10: Dunn test pairwise results between each income class.

Discussion

5.1 WATER CONSUMPTION

Population is the key vector for increases in water consumption at the district level, with a significant positive relationship. As the districts experience growth, it increases the strain on the water supply when there is drought and little regeneration. This result is concurrent with Ruth et al. (2007)'s finding that population is responsible for increasing water demands. Similarly, Wentz and Gober's (2007) models predict that a population increase of one person will increase water demand between 40,720 and 102,714 liters (10,757-27,134 gallons) for a census tract annually. Climate is not as critical to water demand but will be an additional stressor to current supplies in addition to population growth (House-Peters et al., 2010). Ruth et al. discuss that drought restrictions are a great temporary measure to curtail use, but more permanent supply end solutions are needed to increase capacity in growing regions. The state of California does have plans to increase water capacity, but until the infrastructure is operational, they will need to keep restrictions in place to maintain supply. Expected population growth should be factored into future forecasts and the planning of water reclamation infrastructure.

In this study, income was not found to have a significant influence on water consumption. This result does not corroborate the current literature on water demand, which ties income either to increased demand or water intensive land uses. At a large district scale, patterns of socioeconomic heterogeneity are averaged, masking demographic trends in smaller areas and questioning the accuracy of this result (Ashoori et al., 2016). High-income households spend a lower percentage of monthly income on water bills than other income classes, resulting in a higher elasticity in price for increased water consumption (Ashoori et al., 2016). Income is related to land uses and measures, such as residential type (single- or multi-family home) and property size. Single-family homes are often associated with middle- and high-income classes. As income levels increase, property size also increases and with it water intensive activities such as landscaping and pools become more common (Wentz and Gober 2007). High income earners tend to use more water as they can afford larger properties, with water use increasing by 1.8% for every 1,000 sq ft over average lot size (House-Peters et al., 2010). Cooper et al. (2011) confirms that income is a factor in deciding an individual's willingness to pay to avoid drought restrictions, and individuals may be willing to pay up to 25% increase in water bill.

The relationship between population and water use did not change after the Emergency Declaration was made. As the baseline data is from 2020 and the study year was 2022, this may not have been a long enough period for the population to significantly change. If the population does not significantly change over the study period, it is unlikely the relationship will change. We cannot conclude what the relationship between gallons per capita, income, and population is because the results were found to be insignificant. This result may change at different scale, as population and income are both determinants of water consumption.

5.2 DROUGHT RESTRICTION COMPLIANCE

Notifications of water waste had a significant positive relationship with water savings. The study did not include an explanatory variable for this relationship, but the literature suggests that climate may be the underlying factor. Mini et al. (2014) establishes that climate has a role in demand management, as areas with higher temperatures tend to save more water. In these districts, the district is likely employing additional demand management actions to extend water supplies. Haque et al. (2014) found that water savings increased with severity of drought restrictions. Most savings occur from outdoor watering activities in single family homes, which can be easy for homeowners to adapt (Haque et al.). As hotter temperatures are felt by all residents and drought restrictions are widely communicated, residents may feel more inclined to follow restrictions due to heightened awareness of the drought. If residents feel impassioned about saving water and find it morally just, they will follow restrictions (Henser et al., 2006).

It is possible that climate or drought stage may influence the enforcement of restrictions within water districts. If restrictions become more stringent, they may be more challenging for residents to meet, and result in more waste. Length of restrictions may also be a factor in the relationship between water waste notifications and water savings. Cooper et al. (2011) saw that households in long term drought restrictions were willing to pay up to 25% more to avoid restrictions. While other factors such as education, income, and having a lawn also contribute to an individual's willingness to pay out of restrictions (Cooper et al., 2011), it is important to remember that drought restrictions on water use are seen as a temporary solution. Lush, green lawns have been an American standard for many homeowners and are seen as a social norm that homeowners are only willing to temporarily forgo (Sisser et al., 2016). After the period of drought ends, water consumption will return to pre-drought levels, as seen in the 2012-2018 drought period (McCarthy and Dallman, 2019). Districts with high levels of restrictions and hotter climatic conditions may also have greater rates of noncompliance.

There was not a relationship of significance between Notifications and Income, suggesting that most restrictions are being followed at all income levels. Willingness to pay out of drought restrictions may be an increasing concern as the current drought continues. While high water consumption and penalties among celebrities were reported in Summer 2022 (Roth, 2022), this analysis suggests that it is not a common issue of high concern across all water districts at this time.

5.3 INCOME CLASSES AND WATER SAVINGS

The state of California has set a target to reduce water consumption by 15%, but very few districts met the target in 2022. The positive relationship between income and percent water reduction is consistent with the literature findings. Wealthier households have greater property sizes, more water-intensive outdoor features, and more options to limit outdoor use (House-Peters et al., 2010). As outdoor water uses are mainly targeted in water restrictions, some restrictions may not be feasible for those in multi-family housing to meet (Haque et al., 2014). Water districts that serve low-income customers are highly unlikely to meet the 15% reduction target, in this study only two low-income districts met the target. The greatest difference in savings between income classes was between high- and low- income levels.

Uniform reduction targets are unrealistic for some land uses and create challenges for many water districts. In this study, very few water districts met the annual reduction goal of 15% for the 2022 year. Higher income households had a larger median reduction percentage than middle- and low-income classes. Future water reduction targets should factor in land use, socioeconomic, and demographic factors. As most drought restrictions affect outdoor water use, most water savings will be within outdoor water use categories. Tiered reduction targets based on property size may assist water districts with a more equitable distribution of reduction. A large single-family home has a greater water saving potential than a multi-family apartment complex that lacks a lawn and should be required to have a higher reduction target to reflect this.

Water efficient technology often only saves a few gallons of water and takes years to pay for itself with savings (Maggioni, 2015). For multi-family housing that cannot save water from outdoor water restrictions, the few gallons from water efficient appliances may make a difference in savings. As water efficient technology improves, it is expected that indoor water savings will be reduced to 35-40% of 1999 water consumption (Water Research Foundation, 2016) In renter occupied housing, the occupant may not have the control to switch appliances to water efficient options. Cities in California should require water-smart technology in new developments or renovations before issuance of building permits. For low- and middle- income households to cost of water efficient appliances may be cost prohibitive. Toilets make up 24% of indoor water use (Water Research Foundation, 2016) and replacing with water efficient options may provide additional savings to those limited to indoor water reduction. A water efficient toilet can cost between $200-$500 before installation costs, and on average will cost the user between $400-$800 total (Lutz, 2023). California has several rebate programs for water efficient technology, but the programs may not be enough to cover a significant portion of the costs. For example, residents in the City of Bakersfield, California Water Service will give up to $50 for water efficient toilets (California Water Service, 2023). To address the wealth gap in indoor water conservation, water districts should further invest in rebate or grant programs to lower the financial barrier to water saving technology.

5.4 FUTURE RESEARCH

The water use and compliance sections of this analysis should be repeated at a smaller scale for individual districts. The large scale of the project created challenges to analyze trends found within districts. If California water districts repeat the study for their own customers, they be able to see trends in use and compliance among their customers. This would also allow districts to track areas where repeat offenders exist to provide additional conservation resources or mitigation efforts. Similarly, if low-income areas struggle to meet district reduction goals, the district can invest more in providing water efficient technologies or expanding drought communications.

Comparison of penalty systems should also be evaluated to determine which penalty structure reduces repeat offenses, and if there are similarities between water conservation pricing and fine structures. The state has left compliance enforcement up to individual districts and does not have a universal standard for implementing penalties. Flat fees, block pricing, and pricing per unit can all be found in the current fine systems. The literature has established that block pricing is the best conservation tool for water pricing but does not expand on what structure would be most effective in pricing penalties.

Further research should also evaluate how tiered restrictions based on demographics and property compare in savings to universal reduction goals. Most literature on the effectiveness of drought restrictions tie land uses or demographic factors to water consumption. Water districts can set their own regulations and drought restrictions for what would be most effective for their population. Asking all water districts to reduce residential water use by the same amount ignores differences in property size and reduction potential.

Conclusion

As the effects of climate change continue to intensify, the state of California will experience more frequent and intense droughts. While the state has plans to increase water capacity over the coming decades, demand management techniques are used to conserve and extend the current supplies. Water restrictions in combination with increased rates are the most effective temporary measure to reduce water demand during times of drought. This research explores the relationship between income, water use, and drought restriction compliance.

At the district level, population, not income, is a predictor of water consumption, indicating a greater need for water capacity increasing infrastructure. The model was identical for pre- and post- restriction time periods, signifying that there was no change in use with either population or income after restrictions were implemented. When evaluating the relationships between compliance variables, water savings had positive relationships with both income and notifications of water waste. As notifications of water waste and income did not have a relationship of significance, the literature suggests that climate is likely the explanatory variable for the relationship between notifications of water waste and water savings percentage. As temperatures warm and drought stage intensifies, regulations become stricter, and more violations occur. Income’s relationship to water savings informs that as household income increases, the household likely has more opportunities to save water and has the capital to invest in water efficient technology. The biggest difference in water savings percentage between income classes was between low- and high-income classes. Property size has a positive relationship to income, with larger properties having more landscaping, pools, and water intensive uses. Lower income households living in multi-family homes may have a greater challenge reducing consumption as most restrictions target outdoor water use.

Appendix A: Data Dictionary for June 2014 - February 2023 Urban Water Supplier Monthly Reports

For citation, see CSWRCB 2021a.

Monthly Conservation Reporting Definitions and Data Dictionary

Updated June 4, 2021

The following table defines the quantities that are requested in the Monthly Conservation Reporting form.

Variable Name	Definition	Notes
Monthly Total Potable Water Production	Section 990 f of the Water Code: "Total potable water production" means all potable water that enters into a water supplier's distribution system, excluding water placed into storage and not withdrawn for use during the reporting period and excluding water exported outsider the supplier's service area during the reporting period.	This total includes non-revenue water and commercial agriculture (see next note).
Commercial Agricultural Water	Water used for commercial agricultural purposes that meets the definition of Government Code section 51201, subdivision (b). (b) "Agricultural use" means use of land, including but not limited to greenhouses, for the purpose of producing an agricultural commodity for commercial purposes. According to the adopted regulatory text, it includes irrigation of land, irrigation within green houses, frost protection, and heat control. "Commercial agricultural use" does not include cleaning, processing, or other similar post-harvest activities.	While commercial agriculture is not excluded from REPORTED total production, it is subtracted from total production when calculating per capita residential use (see "PRU and R-GPCD Calculation" document).
Commercial, Industrial, and Institutional Water	Water Code, section 10608.12, subdivisions (e), (i), and (j): "Commercial, industrial, and institutional" (CII) means all indoor and outdoor water used by all commercial water users, industrial water users, and institutional water users. CII includes agricultural water and landscape water used for parks, medians, and other outdoor areas associated with CII.	CII includes agricultural water and landscape water used for parks, medians, and other outdoor areas associated with CII.
Recycled Water	Per water code §60301.690, recycled municipal wastewater is recycled water used for indirect potable reuse, such as the effluent from the treatment of wastewater of municipal origin.	
Non-Revenue Water	Includes water lost due to system leaks and thefts, and non-billed water used to fight fires.	
Residential Per Capita Gallons Per Day (R-GPCD)	The average amount of water used per person per day in the supplier service area, in gallons.	See the "PRU and R-GPCD Calculation" document for an explanation of how Water Board staff calculate this quantity.

Urban Water Supplier	Water Code section 10617: A supplier, either publicly or privately owned, providing water for municipal purposes either directly or indirectly to more than 3,000 customers or supplying more than 3,000 acre-feet of water annually. An urban water supplier includes a supplier or contractor for water, regardless of the basis of right, which distributes or sells for ultimate resale to customers. This part applies only to water supplied from public water systems subject to Chapter 4 (commencing with Section 116275) of Part 12 of Division 104 of the Health and Safety Code.	This does not include suppliers when they are functioning solely in a wholesale capacity. “Urban water supplier” does include wholesalers when they are functioning in a retail capacity.

Monthly Conservation Reporting Definitions and Data Dictionary

Updated June 4, 2021

The following table defines all of the data fields that are provided in the Urban Water Supplier Monthly Reports Raw Dataset (located HERE).

Field Name	Data Type	Description	Optional/Mandatory
Supplier Name	Plain Text	Name of the urban water supplier	Mandatory
Public Water System ID	Plain Text	ID number(s) associated with the water system(s) in the supplier service area	Mandatory
Reporting Month	Date	The pertaining month of the Monitoring Report	Mandatory
County	Plain Text	County/counties encompassing the supplier service area	Mandatory
Hydrologic Region	Plain Text	Name of the principal hydrologic region encompassing the supplier's service area	N/A (Prefilled)
Climate Zone	Plain Text	Name of the principal climate zone encompassing the supplier's service area	N/A (Prefilled)
Total Population Served	Number	Estimate of the number of permanent residents served potable water during the reporting month	Mandatory
Reference 2014 Population	Number	Median of 2014 population values as previously reported by suppliers	N/A (Prefilled)
Water Shortage Contingency Plan Stage Invoked	Plain Text	The stage of the water supplier's water shortage contingency plan that has been invoked during the reporting month.	Mandatory
Water Shortage Level Indicator	Plain Text	Indication that reported shortage plan stage corresponds to a shortage greater than 10%	Mandatory
Water Production Units	Plain Text	Units of measure for the reported water production quantities	Mandatory
REPORTED PRELIMINARY Total Potable Water Production	Number	Preliminary estimate of total quantity of potable water produced during the reporting month (excluding water stored or transferred), in reported units	Conditional Mandatory (one of two must be filled)
REPORTED FINAL Total Potable Water Production	Number	Final reported total quantity of potable water produced during the reporting month (excluding water stored or transferred), in reported units	Conditional Mandatory (one of two must be filled)
PRELIMINARY Percent Residential Use	Number	Preliminary estimate of the percentage (as a number out of 100) of total water production that went to residential customers during the reporting month	Conditional Mandatory (one of two must be filled)
FINAL Percent Residential Use	Number	Final reported percentage (as a number out of 100) of total water production	Conditional Mandatory (one of two must be filled)

		that went to residential customers during the reporting month	
REPORTED PRELIMINARY Commercial Agricultural Water	Number	Preliminary estimate of the total quantity of potable water used for commercial agriculture during the reporting month, in reported units	Optional
REPORTED FINAL Commercial Agricultural Water	Number	Final reported total quantity of potable water used for commercial agriculture during the reporting month, in reported units	Optional
REPORTED PRELIMINARY Commercial, Industrial, and Institutional Water	Number	Preliminary estimate of the quantity of potable water used by commercial, industrial, and institutional customers during the reporting month, in reported units	Optional
REPORTED FINAL Commercial, Industrial, and Institutional Water	Number	Final reported quantity of potable water used by commercial, industrial, and institutional customers during the reporting month, in reported units	Optional
REPORTED Recycled Water	Number	Total quantity of recycled water beneficially used during the reporting month, in reported units	Optional
REPORTED Non-Revenue Water	Number	Total quantity of potable water for which supplier does not receive revenue (example: leaks) during the reporting month, in reported units	Optional
CALCULATED Total Potable Water Production Gallons (Ag Excluded)	Number	Total quantity of potable water produced during the reporting month (excluding commercial agriculture and water stored or transferred), in gallons	N/A (Calculated by staff)
CALCULATED Total Potable Water Production Gallons 2013 (Ag Excluded)	Number	Baseline 2013 total potable water production (excluding commercial agriculture) as previously reported by supplier, in gallons	N/A (Prefilled)
CALCULATED Commercial Agricultural Water Gallons	Number	Total quantity of potable water used for commercial agriculture during the reporting month, in gallons	N/A (Calculated by staff)
CALCULATED Commercial Agricultural Water 2013	Number	Baseline 2013 commercial agricultural water production as previously reported by supplier, in gallons	N/A (Prefilled)
CALCULATED R-GPCD	Number	Residential gallons per capita per day	N/A (Calculated by staff)
Qualification	Plain Text	Caveats or additional information about the reported data	Optional

Appendix B: Data Dictionary for October 2020 - December 2022 Water Shortage Drought Response Actions

For citation, see CSWRCB 2021b.

Water Shortage Response Data Dictionary

June 4, 2021

The supplemental Emergency Response section of the Urban Water Supplier Monthly Report is revealed when a reporter selects "Yes" to the question: "Does the [reported invoked Water Shortage Contingency Plan] stage correspond to a shortage greater than 10%, consistent with Water Code section 10632(a)(3)(A)?" This section is formatted as a series of checkboxes corresponding to a list of possible actions the reporter's agency may have taken to address the reported shortage. Additionally, there are a series of questions pertaining to the number of water waste reports received and addressed.

This dataset is limited to the agencies that responded "Yes" to the above question for the reporting month. The data is released as an Excel spreadsheet with two separate tabs:

- The "Listed responses" tab groups all checked actions into a comma-separated list of actions
- The "Machine readable" tab lists each action as a separate column, and checked actions are denoted as a "Y" in the appropriate spreadsheet cell.

The following table defines all of the data fields that are provided in the "Listed responses" tab of the Water Shortage Response Raw Dataset (located HERE).

Field Name	Description
Supplier Name	Name of the urban water supplier
Public Water System ID	ID number(s) associated with the water system(s) in the supplier service area
Reporting Month	The pertaining month of the Monitoring Report
County	County/counties encompassing the supplier service area
Hydrologic Region	Name of the principal hydrologic region encompassing the supplier's service area
Climate Zone	Name of the principal climate zone encompassing the supplier's service area
Water Shortage Contingency Plan Stage Invoked	The stage of the water supplier's water shortage contingency plan that has been invoked during the reporting month.
Demand Actions	Actions in the "Demand" category (see table below) that the agency has taken during the reporting month to address the shortage. Specifically, these actions are intended to reduce per-customer water demand.
Supply Actions	Actions in the "Supply" category (see table below) that the agency has taken during the reporting month to address the shortage. Specifically, these actions are intended to augment the existing service area supply.

Field Name	Description
Water Restrictions	Actions in the "Water Restrictions" category (see table below) that the agency has taken during the reporting month to address the shortage. Specifically, these actions prohibit or limit certain types of water use.
Industry-Specific Actions	Actions in the "Industry-Specific" category (see table below) that the agency has taken during the reporting month to address the shortage. These actions are specific to restaurants, hotels, etc.
Communication Actions	Actions in the "Communication" category (see table below) that the agency has taken during the reporting month to address the shortage. These actions involve increased public messaging regarding the current shortage.
Water Waste Actions	Actions in the "Water Waste" category (see table below) that the agency has taken during the reporting month to address the shortage. Specifically, these actions address problems related to inefficient water use.
Type of water waste	The types of water waste addressed by the reporting agency.
Number of water waste incidents identified or reported	The number of water waste incidents identified or reported for the reporting month.
Number of water waste complaints investigated	The number of waste complaints investigated for the reporting month.
Number of water wasters notified	The number of notifications issued to identified water wasters for the reporting month.

The following table lists the action sub-categories provided in the "Machine readable" tab.

Field Name	Conservation Action Category
Enhanced outreach and communication	Demand
Raising rates	Demand
Apply drought surcharges	Demand
Reduced allocations (for agencies with budget-based rates)	Demand
Residential water audits	Demand
CII water audits	Demand
Expanded existing rebate program	Demand
Rationing	Demand
Turf replacement/rebate	Demand

Field Name	Conservation Action Category
Demand Reduction Other	Demand
Greywater	Supply
On-site treatment and reuse	Supply
Desalination	Supply
Recycled Water	Supply
Remediated Groundwater	Supply
Supply Augmentation Other	Supply
Weekly watering restrictions	Water Restrictions
Excessive irrigation of outdoor landscapes	Water Restrictions
Washing a motor vehicle with a hose not fitted with a shut-off nozzle	Water Restrictions
Application of potable water directly to driveways or sidewalks	Water Restrictions
Use of potable water in decorative water features	Water Restrictions
The application of water to irrigate turf and ornamental landscapes during and within 48 hours after measurable rainfall	Water Restrictions
Restrictions Other	Water Restrictions
Not serving drinking water other than upon request in eating or drinking establishments	Industry-Specific
Operators of hotels and motels providing guests with the option of choosing not to have towels and linens laundered daily	Industry-Specific
Industry Other	Industry-Specific
E-mails	Communication
Paper mail	Communication
Notifications via Customer App	Communication
Website	Communication
Articles/News releases	Communication
Youtube	Communication
Facebook	Communication
Instagram	Communication
Other Social Media	Communication
Community events	Communication
Door hanger	Communication
Workshops	Communication
Television	Communication
Radio	Communication
Billboard	Communication
Paid Media Advertising	Communication
Bus shelter	Communication
Communication Other (Fill-in)	Communication
Notification via customer app	Water Waste
Notification via Phone call	Water Waste
Notification via Letter	Water Waste

Field Name	Conservation Action Category
Notification via Door hanger	Water Waste
Notification via Other	Water Waste
Fine	Water Waste
Assigned a different rate tier	Water Waste
Penalty Other	Water Waste

Works Cited

Ashoori, N., D. Dzombak, M. Small. 2016. "Modeling the Effects of Conservation, Demographics, Price, and Climate on Urban Water Demand in Los Angeles, California." Water Resources Management. 30 (14). [Dordrecht :: Kluwer Academic Publishers: 5247–62. doi:info:doi/.

Bauman, D., J. Boland, and W. M. Hanemann. 1998. *Urban Water Demand Management and Planning*. New York: McGraw-Hill.

Brennan, D., S. Tapsuwan, and D. Ingram. 2007. "The Welfare Costs of Urban Outdoor Water Restrictions." The Australian Journal of Agricultural and Resource Economics 51 (3). Oxford, U.K. :: Blackwell,: 243–61. doi:info:doi/.

Brookshire, D.S., H.S. Burness, J.M. Chermak, and K. Krause. 2002. "Western Urban Water Demand." Natural Resources Journal. 42 (4). [Albuquerque] :: University of New Mexico, School of Law: 873–98. doi:info:doi/.

Brown, E.G. 2015. "Executive Order B-29-15." State of California Governor's Office. https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/040115_executive_order.pdf.

California Natural Resources Agency. 2021. "Report to the Legislature on the 2012–2016 Drought." https://water.ca.gov/-/media/DWR-Website/Web-Pages/Water-Basics/Drought/Files/Publications-And-Reports/CNRA-Drought-Report-final-March-2021.pdf.

California Natural Resources Agency. 2022. "California's Water Supply Strategy - Adapting to a Hotter, Drier Future." https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf

California State Water Resources Control Board. 2021a. "Monthly Conservation Reporting Definitions and Data Dictionary." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/docs/definitions_and_data_dictionary_accessible.pdf

California State Water Resources Control Board. 2021b. "Water Shortage Response Data Dictionary." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/docs/emergency_response_data_dictionary_accessible.pdf

California State Water Resources Control Board. 2022a. "Resolution 2022-0002 To Adopt

Emergency Regulation to Supplement Voluntary Water Conservation." https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2022/rs2022_0002.pdf.

California State Water Resources Control Board. 2022b. "State Water Board releases draft emergency water conservation regulation." https://www.waterboards.ca.gov/press_room/press_releases/2022/pr05132022-draft-emergency-water-conservation-regulations.pdf

California State Water Resources Control Board. 2023a. "Conservation Water Pricing." https://www.waterboards.ca.gov/drought/pricing/.

California State Water Resources Control Board. 2023b. "June 2014 - February 2023 Urban Water Supplier Monthly Reports." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html.

California State Water Resources Control Board. 2023c. "October 2020 - February 2023 Water Shortage Drought Response Actions." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html.

California State Water Resources Control Board. 2023d. "System Area Boundary Layer Look-up Tool." https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=272351aa7db14435989647a86e6d3ad8

California State Water Resources Control Board. 2023e. "Water Conservation Portal – Conservation Reporting." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html.

California State Water Resources Control Board. 2023f. "Water Conservation Portal – Emergency Conservation Regulation." https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/regs/emergency_regulation.html#reg.

California State Water Resources Control Board. 2023g. "Water Recycling Funding Program (WRFP)" https://www.waterboards.ca.gov/water_issues/programs/grants_loans/water_recycling/.

California Water Service. 2023. "Rebates." https://www.calwater.com/conservation-rebates/.

City of Fresno Department of Public Utilities. “Regulations, Enforcement & Appeals.” https://www.fresno.gov/publicutilities/water-conservation-program/regulations-enforcement-appeals/.

Cooper, B., M. Burton, and L. Crase. 2011. “Urban Water Restrictions: Attitudes and Avoidance.” Water Resources Research. 47 (12). [Washington, D.C.] :: American Geophysical Union. doi:info:doi/.

Dixon, G. 2021. “California Zip Codes.” California State Geodata Portal. https://gis.data.ca.gov/datasets/CDEGIS::california-zip-codes/explore

Edwards. 2006. “Whose Values Count? Demand Management for Melbourne’s Water.” The Economic Record 82 (s1). [Oxford, U.K.] :: Blackwell Publishers: 54–63. doi:info:doi/.

Fisher-Jeffes, L., G. Gertse, and N.P. Armitage. 2015. “Mitigating the Impact of Swimming Pools on Domestic Water Demand.” Water S. A. 41 (2). Water Research Commission (WRC): 238–46. doi:10.4314/wsa.v41i2.09.

Gaughan, G. 2020. “All Dried Up: Averting the Day Zero Water Crisis Through Tax Reform.” The San Diego Law Review 57 (1). San Diego: University of San Diego, School of Law: 223–.

Haque, M., D. Hagare, A. Rahman, and G. Kibria. 2014. “Quantification of Water Savings Due to Drought Restrictions in Water Demand Forecasting Models.” Journal of Water Resources Planning and Management 140 (11). American Society of Civil Engineers: 4014035–. doi:10.1061/(ASCE)WR.1943-5452.0000423.

Hensher, D., N. Shore, and K. Train. 2006. “Water Supply Security and Willingness to Pay to Avoid Drought Restrictions.” The Economic Record 82 (256). Oxford, UK and Boston, USA: Blackwell Publishing, Inc: 56–66. doi:10.1111/j.1475-4932.2006.00293.x.

House-Peters, L., B. Pratt, and H. Chang. 2010. “Effects of Urban Spatial Structure, Sociodemographics, and Climate on Residential Water Consumption in Hillsboro, Oregon1.” Journal of the American Water Resources Association 46 (3). Oxford, UK: Blackwell Publishing Ltd: 461–72. doi:10.1111/j.1752-1688.2009.00415.x.

Internal Revenue Service. 2021. “SOI Tax Stats - Individual Income Tax Statistics - 2020 ZIP Code Data (SOI).” https://www.irs.gov/statistics/soi-tax-stats-individual-income-tax-statistics-2020-zip-code-data-soi.

Irwin, N., S. McCoy, and I. McDonough. 2021. “Water in the Time of Corona(Virus): The Effect of Stay-at-Home Orders on Water Demand in the Desert.” Journal of Environmental Economics and Management 109: 102491. https://doi.org/10.1016/j.jeem.2021.102491.

Kenney, D.S., C. Goemans, R. Klein, J. Lowery, and K. Reidy. 2008. “Residential Water Demand Management: Lessons from Aurora, Colorado.” Journal of the American Water Resources Association / 44 (1). Herndon, Va. :: American Water Resources Association,: 192–207. doi:info:doi/.

Krause, K., J.M. Chermak, and D.S. Brookshire. 2003. “The Demand for Water: Consumer Response to Scarcity.” Journal of Regulatory Economics. 23 (2). Norwell, MA :: Kluwer Academic Publishers: 167–91. doi:info:doi/.

Las Virgenes Municipal Water District. “Administrative Penalties.” Accessed February 2023. https://www.lvmwd.com/for-customers/water-budgets/administrative-penalties.

Linnartz, Kathryn. 2021. “Texas Groundwater: Balancing Individual Property Rights With a Depleting Natural Resource.” Texas Tech Law Review 53 (4). Texas Tech University School of Law: 773–.

Lutz, A. 2023. “How Much Does It Cost to Install a Toilet?” Architectural Digest. https://www.architecturaldigest.com/reviews/home-improvement/new-toilet-cost.

Maggioni, E. 2015. “Water Demand Management in Times of Drought: What Matters for Water Conservation.” Water Resources Research. 51 (1). [Washington, D.C. :: American Geophysical Union: 125–39. doi:info:doi/.

McCarthy, M., and S. Dallman. 2019. “The Drought Is Over—Now What?” Yearbook – Association of Pacific Coast Geographers 81 (1). University of Hawai’i Press: 112–34. doi:10.1353/pcg.2019.0014.

Mini, C., T.S. Hogue, and S. Pincetl. 2014. “The Effectiveness of Water Conservation Measures on Summer Residential Water Use in Los Angeles, California.” Resources, Conservation, and Recycling 94 (C). [Amsterdam :: Elsevier Science BV: 136–45. doi:info:doi/.

Mount, J., and E. Hanak. 2014. “Water Use in California.” PPIC Water Policy Center. https://cwc.ca.gov/-/media/CWC-Website/Files/Documents/2019/06_June/June2019_Item_12_Attach_2_PPICFactSheets.Pdf

Mullin, M., and M.E. Rubado. 2017. “Local Response to Water Crisis: Explaining Variation in Usage Restrictions During a Texas Drought.” Urban Affairs Review (Thousand Oaks, Calif.) 53 (4). Los Angeles, CA: SAGE Publications: 752–74. doi:10.1177/1078087416657199.

Newsom, G. 2019. “Executive Order N-10-19.” State of California Executive Department. https://www.gov.ca.gov/wp-content/uploads/2019/04/4.29.19-EO-N-10-19-Attested.pdf.

Newsom, G. 2021a. “Executive Order N-7-21.” State of California Executive Department. https://www.gov.ca.gov/wp-content/uploads/2021/06/6.11.21-EO-N-07-21-signed.pdf

Newsom, G. 2021b. “Proclamation of a State of Emergency.” State of California Executive Department. https://www.gov.ca.gov/wp-content/uploads/2021/10/10.19.21-Drought-SOE-1.pdf.

Newsom, G. 2022. “Executive Order N-7-22.” State of California Executive Department. kennthttps://www.gov.ca.gov/wp-content/uploads/2022/03/March-2022-Drought-EO.pdf.

Nobert, Matthew. 2022. “What You Need to Know about Water Restrictions and Fines in Southern California.” KTLA. https://ktla.com/news/california/california-cities-introduce-rules-and-fines-on-water-use-during-the-drought/.

National Resources Defense Council. 2014. “Urban Water Conservation and Efficiency Potential in California.” https://www.nrdc.org/sites/default/files/ca-water-supply-solutions-urban-IB.pdf

Palmdale Water District. “Mandatory Water Conservation Information Sheet.” April 2022. https://www.palmdalewater.org/wp-content/uploads/2022/05/Mandatory_Conservation-2022.pdf.

Pérez-Urdiales, M., and K.A. Baerenklau. 2020. “Assessing the Impacts of Urban Water-Use Restrictions at the District Level: Case Study of California’s Drought Mandate.” Journal of Water Resources Planning and Management 146 (5). New York: American Society of Civil Engineers. doi:10.1061/(ASCE)WR.1943-5452.0001169.

Pincetl. 2016. “Fragmented Flows: Water Supply in Los Angeles County.” Environmental Management. 58 (2). [New York],: Springer-Verlag: 208–22. doi:info:doi/.

Ruth, M., C. Bernier, N. Jollands, and N. Golubiewski. 2007. “Adaptation of Urban Water Supply Infrastructure to Impacts from Climate and Socioeconomic Changes: The Case of Hamilton, New Zealand.” Water Resources Management 21 (6). Dordrecht: Dordrecht : Kluwer Academic Publishers: 1031–45. doi:10.1007/s11269-006-9071-x.

Sisser, J.M., K.C. Nelson, K.L. Larson, L.A. Ogden, C. Polsky, and R.R. Chowdhury. 2016. “Lawn Enforcement: How Municipal Policies and Neighborhood Norms Influence Homeowner Residential Landscape Management.” Landscape and Urban Planning 150. Elsevier B.V: 16–25. doi:10.1016/j.landurbplan.2016.02.011.

State of California Office of Administrative Law. 2022. “2022-0606-03 Notice of Approval of

Emergency Regulatory Action.” https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/regs/docs/2022-0606-03E-approval.pdf

U.S. Census Bureau. 2023. “QuickFacts: California.” https://www.census.gov/quickfacts/fact/table/CA/INC110221.

Water Research Foundation. 2016. “Residential End Uses of Water, Version 2: Executive Report.” https://www.awwa.org/Portals/0/AWWA/ETS/Resources/WaterConservationResidential_End_Uses_of_Water.pdf

Wentz, E., and P. Gober. 2007. “Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona.” Water Resources Management 21 (11). Dordrecht: Dordrecht : Springer Netherlands: 1849–63. doi:10.1007/s11269-006-9133-0.